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Debris-covered glaciers during glacial and interglacial periods on the Taurus Mountains (Turkey)

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Abstract

The debris-covered glaciers are observed all over the glaciation regions of the world (Alps, Antarctica, Greenland, Andes, Cascades, Rocky Mountains and etc.). The debris covered glaciers are known as the formations which occur in the retreating phase of glaciers and sometimes they are confused with rock glaciers. In this study, hypothesis that debris covered glaciers existed in glaciation fields with similar conditions during the previous glacial periods in Pleistocene is questioning. The experiences which are acquired from actual glaciers in Taurus range and the researches that have been done in the other glaciated valleys of the world shows apparent evidence that there were debris-covered glaciers in the past glacial periods and also debris layer can be found during the advancing phase of a glacier. From the valleys that are occupied with debris-covered glaciers the following conclusions have been extended. When they have compared to past bare glaciers, past debris-covered glaciers a) responded later to warm air and temperature rise, b) advanced to lower altitudes, c) experienced different sediment transport and deposit from bare glaciers, d) didn't experienced ablation from the surface of the glacier slowly, but faster ablation due to collapsing and calving of subglacial-englacial channels, e) maintained themselves as fully covered dead ice/glaciers in protected cirque areas in the last stage of glaciation. If the retreating of the glacier continues until it is completely covered by the debris layer, than it may become an ice-cored rock glacier.

Keywords: Debris-covered glaciers; environmental responses; mass balance; glacial sediment transfer; Taurus Mountains.

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1. Introduction

Snow, ice and rock particles are common in high mountainous areas. Each of these three elements has a different role in the formation of glaciers and rock glaciers, and their amounts vary over time and space, depending on environmental conditions. If the amount of snow and ice is more than that of debris material, clean or bare glaciers result. On the other hand, debris-covered glaciers form where the rock component is relatively high, and debris accumulates as a lag on the ablation zone of the dirty ice mass. The geographical formation whose rock content is high enough to insulate snow and ice is known as a rock glacier (Benn et al., 2005, p. 395)

In recent years, debris-covered glaciers have become a popular topic in glacier research. These glaciers differ from uncovered or rock glaciers with their mass balance, movement mechanisms, energy transfer, response to environmental changes and hydrological-biological characteristics. While their most typical examples can today be found in the Himalayas and New Zealand Alps, this type of glacier actually exists in all glacial areas around the globe. This study questions hypothesis that debris covered glaciers, whose typical examples can also be seen on the Aladağ Mountain Range as mentioned by Gürgen et al. (2010b), Karçal Mountains (Gürgen & Yeşilyurt, 2012) and Bolkar Mountain's (Çalışkan et al., 2012) existed in glaciation fields with similar conditions during the previous geological stages.

2. Pleistocene debris-covered glaciers

Natural laws and processes that operate in the universe now, have always operated in the universe in the past and apply everywhere in the universe. "The present is the key to the past". The formation processes and characteristics of actual debris-covered glaciers are the most evident indicator that they used to form in areas with similar conditions in the past. The interaction that these types of glaciers have with their environment today also represents their past interactions. This suggests that debris-covered glaciers in the past also responded to climate change differently from uncovered glaciers. Research in Turkey provides evidence for debris-covered glaciers in a major part of valleys that were glaciated during the Pleistocene.

2.1. Pleistocene debris-covered glaciers and their environmental interactions

The key factor that differentiates the interaction between debris-covered glaciers and their environment from that of uncovered glaciers with bare ice and rock glaciers is the material covering them. The mass balance of a glacier depends on the accumulation of glacial ice and the ablation of this ice at its surfaces. When the debris cover on the glacier is thicker than 2-3cm, it acts as protection from radiation and reduces glacial ablation by 25-40%. The amount of glacial ablation is in reverse proportion to the thickness of the debris-covered cover. A layer thicker than 50 cm can even eliminate ablation (Kayastha et al. 2000; Nakawo & Rana, 1999; Pelto, 2000; Shroder et al.2000; Singh et al. 2000; Takeuchi et al. 2000). Debris-covered covered glaciers have a different accumulation-ablation balance than the glaciers where the ice is exposed. Their volume balance is determined as much by internal factors as external ones, such as radiation, amount of precipitation and avalanches. Their movements are also different. Glaciers are not only made of glacial ice but also include moraine or other materials inside or covering them. When debris-covered glaciers are considered, the englacial and subglacial moraines and the debris material they carry become significant factors that determine the movement style (Gürgen et al.2010a). The insulation afforded by the debris cover is an important factor that limits glacier retreating in our day. The actual glaciers in Taurus Ranges owe their existence to their debris layers. The hypothesis, that the mountain ranges with debris-covered glaciers today were also covered in past glacial stages, suggests that the response of these glaciers to temperature rise will also be different to uncovered/bare glaciers.

2.2. Volume balance in Pleistocene debris-covered glaciers

The main factor that determines the movement of glaciers is their mass balance. As in many glaciers today, the ablation area losses of Pleistocene glaciers that were uncovered in the accumulation area and covered in the ablation area would have been significantly decreased.

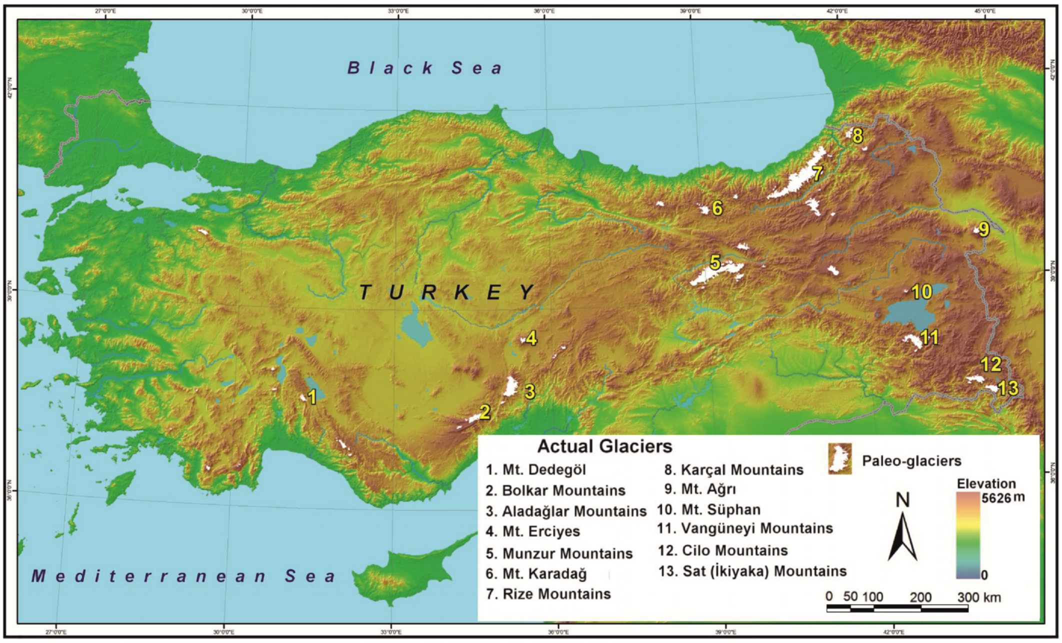

Fig. 1. The actual glaciers of Turkey (adopted from Çiner, 2003: pp. 58).

Factors that limit ablation cause fewer deficits in the glacial budget and thus enable a glacier advance. This was observed when the surface elevation and volume of the covered tongue of the Miage glacier in Italy increased between 1913 and 1999 and the glacier progressed (Tomphson et al. 2000). Another interesting example showing the quality of the relationship between debris layer and glacial volume balance is the Emmons Glacier (Rainier Mountains/USA). A large rock avalanche partially covered the previously uncovered glacier in 1963. After the lower parts of the glacier became covered with debris material, it advanced with pace until 1992. After 1992, the glacial advance slowed down and a retreating stage started. The glacier was reported to leave behind “hummocky areas” as it retreats (Driedger, 1993). The hummocky areas that show retreating in Pleistocene debris-covered glaciers have been observed in the Taurus range (Çalışkan, et al., 2012; Çiner, 2003; Çiner et al. 1999). While the mean altitude that glacial tongues extend to in the Eastern Black Sea Mountains was approximately 1800-2000 m (Akçar et al., 2007; Doğu et al. 1996; Doğu et al. 1998; Doğu et al. 1994; Doğu et al. 1993), some glaciers in the Taurus Mountains extend much lower (1200-1800 m) (Blumenthal, 1956; Doğu et al.1999; Sarıkaya et al.2009; Zahno et al.2009). However, when compared, the Eastern Black Sea Mountain Range is where glacial conditions would be expected to be more intense owing to its more northerly latitude and higher altitude. Most of the existing glaciers and glaciated valleys in Turkey are located in the Eastern Black Sea Mountains. Glaciers being higher can only be explained by the Black Sea being a fresh water lake in the Last Glacial Maximum. Less humidity in the atmosphere in the region may lead to the conclusion that effective precipitation may be less; however, this assumption is not supported by the sapropel layer seen in the more shallow parts of the southeastern Black Sea (250m from the surface), unlike its northern shores (Hay & Honjo, 1989). The intensity of glaciation is also affected by the amount of effective precipitation, size of feeding area, pre-glaciation topography and lithology control, and debris material coverage. Thus, debris covers are thought to be an important factor in the lower Pleistocene glaciers on the Taurus Mountains when compared to other glaciation areas in Turkey (Fig. 1).

Another factor suggesting that the Pleistocene glaciers of the Taurus range were not bare alpine glaciers but debris-covered ones is the fact that they continued into a later period. The date determined for the Hacer Valley, a Pleistocene glacial valley in Turkey, is the limit of the Pleistocene-Holocene (Zreda et al. 2012). The existence of debris-covered glaciers has been confirmed by studies of the upper parts of this valley (Gürgen, et al., 2010b). Just as debris-covered glaciers are protected under the permanent snowline today, despite a warmer climate, a similar effect was true in the past. Despite the temperature rise in the Pleistocene, the debris cover helped protect the glaciers and enabled them to respond later than uncovered glaciers to the warming climate.

Melting and ablation in uncovered glaciers mostly occur from the surface. Surface ablation in debris-covered glaciers depends on the thickness of the cover and is reduced to almost zero at 40-50 cm cover thickness. Ablation in this type of glacier is generally englacial and/or subglacial. While the glacier does not lose significant volume from the surface and protects its thickness, channels and tunnels underneath continue to develop. This is the most important element in the formation of supraglacial lakes, which are only seen in debris-covered glaciers, and distinguish them from uncovered and rock glaciers. Forming due to subglacial eruptions or temperature rise over ice sheets in volcanic areas, this type of lake does not occur on alpine glaciers. Supraglacial lakes form in areas where the subglacial channels expand and collapse over time (Fig. 2). Having an important role in the identification of debris-covered glaciers as well; supraglacial lakes are among the main factors affecting mass balance. Previous experimental researches have shown that the ice cliffs of these lakes are the weakest parts of debris-covered glaciers with respect to ablation (Konrad, 1998; Krainer & Mostler, 2000; Nakawo & Rana, 1999). Thus we can assume that when the advance of Pleistocene glaciers was halted and the glacier became static, subglacial channels started to collapse and supraglacial lakes appeared.

Fig. 2. Kopuk Glacier and its supraglacial lakes (Bolkar Mountains, Turkey).

This set off a chain reaction in the glacier, which up until this point had been well insulated from environmental conditions, and particularly temperature rise. With the formation of supraglacial lakes, exposed ice surfaces appeared at ice cliffs of the lakes and ablation increased. The glacier started to calving, thus melting faster. Subglacial barrier lakes formed behind the collapsed channels. The collapse or outburst of these barriers leads to catastrophic floods. Apart from ablation caused by floods, new collapses occur in the areas left behind by the subglacial lakes. All this cracking, collapsing and calving in the glacier speeds up retreating (Fig. 3). As a result of climate change (cooling), the glacier starts to be fed again, thus stopping all of these ablation processes and advancing of the glacier by including all debris, which had been left behind at the time of retreating.

2.3. Sediment transport in Pleistocene debris-covered glaciers

Today, there is a large amount of disintegrated material in the glacial valleys of the Taurus Mountains. This material is in the form of talus and is located on valley and cirque slopes. It is also possible to observe this talus material on existing glaciers. Considering the similarity of conditions, it is obvious that this material also covered glaciers in this area during the Pleistocene. The material that covered the Pleistocene glaciers is seen on the Taurus Mountains today as moraine and breccia deposits. In addition, the material carried by subglacial currents and the rivers fed by the glaciers was deposited in the lower sections of the valleys as conglomerate.

Debris material has been observed to easily adhere to covered glaciers, even on sloped surfaces. The main geological formation of Taurus Range is limestone. Limestone derived calcium in the debris leads to the cementation of the cover, grains of debris are thus locked together firmly and they stay that way. This cover is durable against physical weathering and is affected only by chemical dissolution. Similar formations would also have been effective under Pleistocene conditions. Furthermore, when the glaciers receded and the cover was left on the valley floor, cementation would have had a major role in combining these deposits into rock.

Spedding's (2000) study on the Gigjökull and Kviarjökull (Iceland) glaciers offered a new perspective to sediment transport in debris-covered glaciers. The valleys of these two partially covered glaciers do not include base moraines or till deposits. They attribute this to the fact that the insulation provided by the debris over the glacier turns englacial channels into subglacial currents, which then transport till and base moraines. As a consequence of this transport, the moraine and till deposits that are observed under alpine glaciers do not exist under these ones. Similarly, today's valleys that host debris-covered glaciers do not contain the deposits that normally exist in mountain-valley glaciers. This is generally attributed to the fluvial processes following glaciation. As the hydrological conditions of debris-covered glaciers are different, these deposits may get eliminated or transported during glaciation. Important evidence for this is the hummocky areas that are observed below debris-covered glacial valleys.

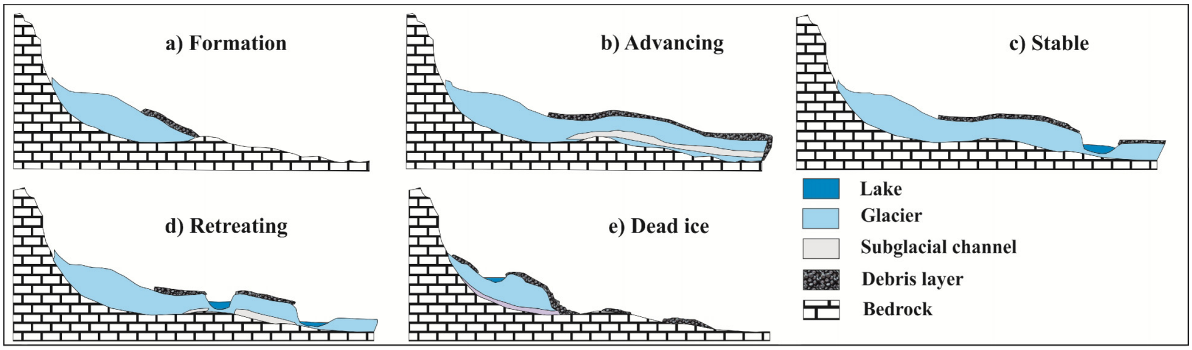

Fig. 3. Formation and development of debris covered glaciers. a) In the formation stage, the glacier moves with its accumulation area uncovered and ablation area covered. b) As ablation will be less during advancing, it extends way below uncovered glaciers and form englacial-subglacial channels. c) In the stable stage, even if the ablation rate stays the same, the glacier cannot advance as it is not fed from behind, and englacial-subglacial channels start to collapse and supraglacial lakes form. d) In the retreating stage, as collapses cause more bare ice surface and owing to calving, ablation increases greatly. Outbursts in glacial lakes may lead to the elimination of moraine deposits. e) Covered glaciers appear as dead ice locked in cirques in their last stages. When the debris covers the entire glacier, it may turn into a rock glacier.

3. Conclusion

Debris-covered glaciers are mountain-valley glaciers and/or glacial tongues permanently insulated by material carried over them from surrounding areas. Similar to many glaciation areas throughout the world, current examples of these glaciers exist on the Taurus Mountain Range. The cover layer changes the environmental interaction of the glacier, causes it to respond less and later to temperature rise, prevent ablation and may make it progress despite the warming climate. Therefore, along with climate, effective precipitation, feeding style of the glacier and pre-glaciation topography, debris cover is another important factor that determines the mass balance of a glacier and the intensity of glaciation. Covered mountain-valley glaciers require a minimum proportion of constituent snow-ice and debris material. The characteristics of the underlying geology and climatic conditions determine the amount of the debris material. Fragmented, cracked rocks with physical and chemical characteristics that allow disintegration will naturally produce more debris material. Considering that today's natural processes were the same in the past, the glaciation areas that host debris-covered glaciers today, must have hosted debris-covered glaciers in the past as well.

When debris-covered glaciers are compared to uncovered ones from the Pleistocene, they are seen to have:

1. Responded later to warmth and temperature rise,
2. Extended to lower altitudes,
3. Experienced different sediment transport and storage from uncovered glaciers,
4. Not experienced slow ablation from the surface of the glacier, but faster ablation due to collapsing and calving of subglacial-englacial channels,
5. Maintained themselves as fully covered dead ice/glaciers in protected cirque areas in the final stage of glaciation.

Similar to many of the world's actual debris-covered glaciers, it is possible to see signs in Pleistocene glaciation areas on the Taurus Mountains. Our understanding of Pleistocene glaciation in the Taurus Mountains is been informed by studies of existing debris-covered glaciers. These glaciers respond differently to environmental conditions when compared to bare glaciers. Determining these differences in actual glaciation areas may shed light on previous environmental changes as well.

References

Akçar, N.; Yavuz, V.; Ivy-Ochs, S.; Kubik, P.W., Vardar, M.; Schlüchter, C. (2007). A case for a downwasting mountain glacier during Termination I, Verçenik valley, northeastern Turkey. Journal of Quaternary Sciences, 23(1), 273-285.

Benn, I.D.; Kirkbride, P.M.; Owen, A.L.; Brazier, V. (2005). Glaciated Valley Landsystems. In D. J. A. Evans (Ed.), Glacial Landsystems (pp. 372-406). New York: Oxford University Press.

Blumenthal, M.M. (1956). Yüksek Bolkardağın kuzey kenar bölgelerinin ve batı uzantılarının jeolojisi (Güney Anadolu Torosları). Ankara: Maden Tetkik ve Arama Enstitüsü Yayınları Seri No: 7.

Çalışkan, O.; Gürgen, G.; Yılmaz, E.; Yeşilyurt, S. (2012). Glacial morphology and debris-covered glaciers of northeast of Bolkar Mountains (Vol. 9).

Çiner, A. (2003). Türkiye'nin Güncel Buzulları ve Geç Kuvaterner Buzul Çökelleri. Türkiye Jeoloji Bülteni, 46, 55-78.

Çiner, A.; Deynoux, M.; Çörekçioğlu, E. (1999). Hummocky moraines in the Namaras and Susam Valleys, Central Taurids, SW Turkey. Quaternary Science Reviews, 18, 659-669.

Doğu, A.F.; Çiçek, İ.; Gürgen, G.; Tunçel, H. (1996). Üçdoruk (Verçenik) Dağında Buzul Şekilleri, Yaylalar ve Turizm. Ankara Üniversitesi, Türkiye Coğrafyası Araştırma ve Uygulama Merkezi Dergisi, 5, 29-51.

Doğu, A.F.; Çiçek, İ.; Gürgen, G.; Tunçel, H. (1998). Bulut-Altıparmak Dağlarında Buzul Şekilleri, Yaylalar ve Turizm. Ankara Üniversitesi, Türkiye Coğrafyası Araştırma ve Uygulama Merkezi Dergisi, 6, 63-92.

Doğu, A.F.; Çiçek, İ.; Gürgen, G.; Tunçel, H.; Somuncu, M. (1994). Göller (Hunut) Dağında Buzul Şekilleri, Yaylalar ve Turizm. Ankara Üniversitesi, Türkiye Coğrafyası Araştırma ve Uygulama Merkezi Dergisi, 3, 195-218.

Doğu, A.F.; Çiçek, İ.; Tunçel, H.; Gürgen, G. (1999). Akdağ'ın Jeomorfolojisi ve Bunun Beşeri Faaliyetler Üzerine Etkisi (Fethiye-Muğla). Ankara Üniversitesi, Türkiye Coğrafyası Araştırma ve Uygulama Merkezi Dergisi, 7, 95-120.

Doğu, A.F.; Somuncu, M.; Çiçek, İ.; Tunçel, H.; Gürgen, G. (1993). Kaçkar Dağında Buzul Şekilleri, Yaylalar ve Turizm. Ankara Üniversitesi, Türkiye Coğrafyası Araştırma ve Uygulama Merkezi Dergisi, 2(157-183), 157.

Driedger, C.L. (1993). Glaciers on Mount Rainier.

Gürgen, G.; Çalışkan, O.; Yılmaz, E.; Yeşilyurt, S. (2010a). Döküntü örtülü buzullar ve kaya buzulları. [Article]. e-Journal of New World Sciences Academy, 5(1), 32-45.

Gürgen, G.; Çalışkan, O.; Yılmaz, E.; Yeşilyurt, S. (2010b). Yedigöller Platosu ve Emli Vadisinde (Aladağlar) dökünütü örtülü buzullar. [Article]. e-Journal of New World Sciences Academy, 5(2), 98-116.

Gürgen, G.; Yeşilyurt, S. (2012). Karçal Dağı Buzulları (Artvin). Coğrafi Bilimler Dergisi, 10(1), 91-104.

Hay, B.; Honjo, S. (1989). Particle Deposition in the Present and Holocene Black Sea. Oceanography, 2, 26-31.

Kayastha, R.B.; Takeuchi, Y.; Nakawo, M.; Ageta, Y. (2000). Practical prediction of ice melting beneath various thickness of debris cover on Khumbu Glacier, Nepal, using a positive-degree day factor. In M. Nakao, A. Fountain & C. F. Raymond (Eds.), Debris-covered Glaciers. Washington: IAHS Publication.

Konrad, S. K. (1998). Possible outburst floods from debris-covered glaciers in the Sierra Nevada, California. Geografiska Annaler, 80, 183-192.

Krainer, K.; Mostler, W. (2000). Reichenkar rock glacier: a glacier derived debris-ice system in the Western Stubai Alps, Austria. Permafrost and Periglacial Processes, 11, 267-275.

Nakawo, M.; Rana, B. (1999). Estimate of ablation rate of a glacier ice under supraglacial debris layer. Geografiska Annaler, 81(695-701).

Pelto, S.M. (2000). Mass balance of adjacent debris-covered and clean glacier ice in the North Cascades, Washington. In M. Nakao, A. Fountain & C. F. Raymond (Eds.), Debris-covered Glaciers (pp. 35-42). Washington: IAHS Publication.

Sarıkaya, M.A.; Zreda, M.; Çiner, A. (2009). Glaciations and paleoclimate of Mount Erciyes, central Turkey, since the Last Glacial Maximum, inferred from 36Cl cosmogenic dating and glacier modeling. Quaternary Science Reviews, 28(23–24), 2326-2341.

Shroder, F.J.; Bishop, P.M.; Copland, L.; Sloan, V.F. (2000). Debris-covered glaciers and rock glaciers in the Nanga Parbat Himalaya, Pakistan. Geografiska Annaler, 82, 17-31.

Singh, P.; Kumar, N.; Ramasastri, K.S.; Singh, V. (2000). Influence of a fine debris layer on the melting of snow and ice on a Himalayan glacier. In M. Nakao, A. Fountain & C. F. Raymond (Eds.), Debris-covered Glaciers (pp. 63-69). Washington: IAHS Publication.

Spedding, N. (2000). Hydrological controls on the sediment transport pathways: implications for debris-covered glaciers. In M. Nakao, A. Fountain & C. F. Raymond (Eds.), Debris-covered Glaciers (pp. 133-142). Washington: IAHS Publication.

Takeuchi, Y.; Kayastha, B.R.; M., N. (2000). Characteristics of ablation and heat balance in debris-free and debris-covered areas on Khumbu Glacier, Nepal Himalayas, in the pre-monsoon season. In M. Nakao, A. Fountain & C. F. Raymond (Eds.), Debris-covered Glaciers (pp. 53-61). Washington: IAHS Publication.

Tomphson, M.H.; Kirkbride, M.P.; Brock, B.W. (2000). Twentieth century surface elevation change of the Miage Glacier, Italian Alps. In M. Nakao, A. Fountain & C. F. Raymond (Eds.), Debris-covered Glaciers (pp. 219-225). Washington: IAHS Publication.

Zahno, C.; Akçar, N.; Yavuz, V.; Kubik, P.W.; Schlüchter, C. (2009). Surface exposure dating of Late Pleistocene glaciations at the Dedegöl Mountains (Lake Beyşehir, SW Turkey). Journal of Quaternary Sciences, 24, 1016-1028.

Zreda, M.; Çiner, A.; Sarıkaya, M.A.; Zweck, C.; Bayarı, S. (2012). Remarkably extensive glaciation in Turkey near the Pleistocene-Holocene boundary. Geology, 39(11), 1051-1054.